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Performance analysis of heat pumps utilizing different low temperature heat sources to supply district heating

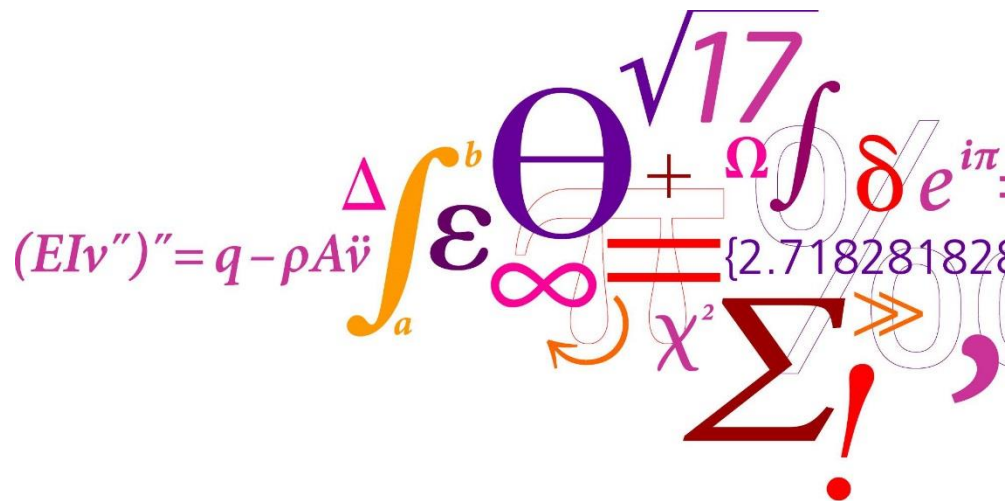
3rd international Conference on Smart Energy Systems and
4th Generation District Heating
12.-13. September 2017, Copenhagen

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Torben Ommen

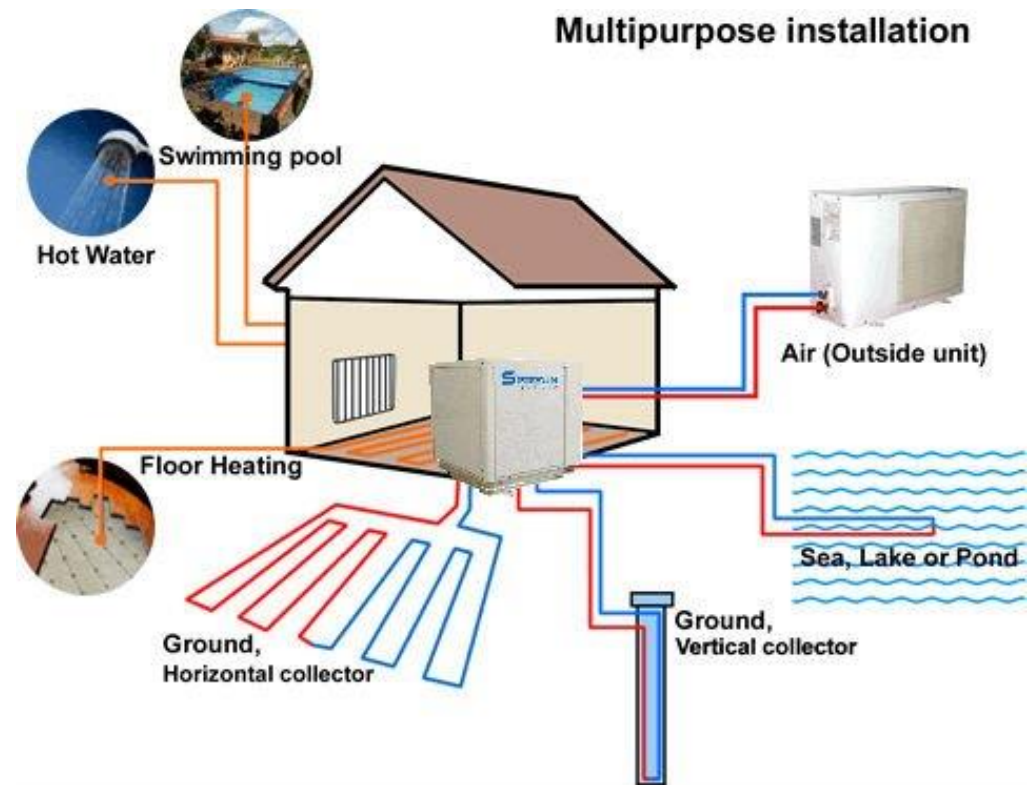
Wiebke Brix Markussen

Brian Elmegaard



Agenda

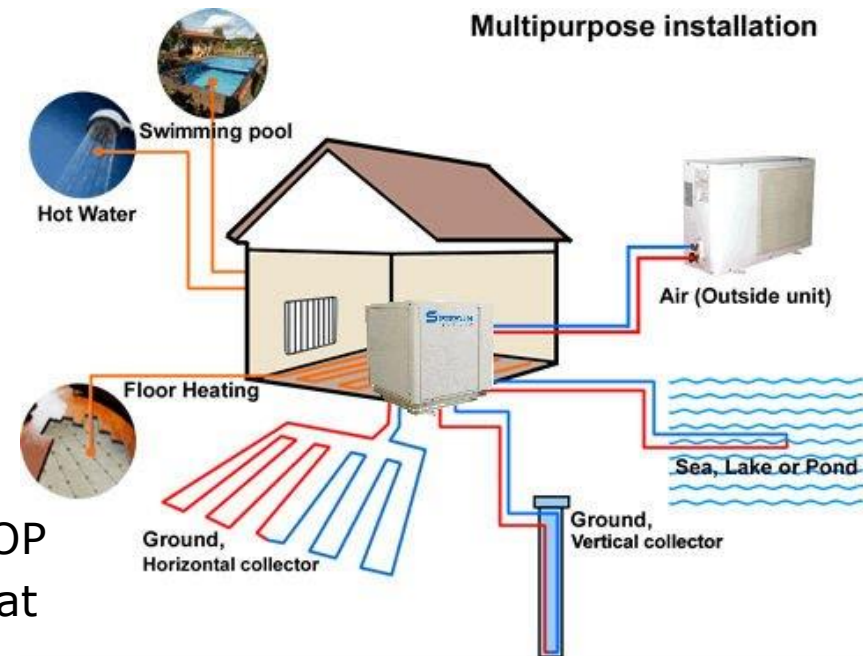
- I. Introduction
 - Motivation
- II. Method
 - Model development
 - Key parameters
 - Case description
- III. Results
 - Comparison of scenarios
- IV. Discussion
 - Model limitations
- V. Conclusion



Source: <http://www.heatpumpcritique.com/>

I. Introduction

- Energy planning:
 - Constant COP of heat pumps (HP)
- Different heat sources:
 - Seawater, lakes, rivers
 - Air, solar energy
 - Groundwater, geothermal energy
 - Sewage water, waste heat
- Varying temperatures:
 - Influence COP
- How to get highest COP?
 - Investigating hourly variations in COP
 - Comparing scenarios with single heat sources and a combination of those



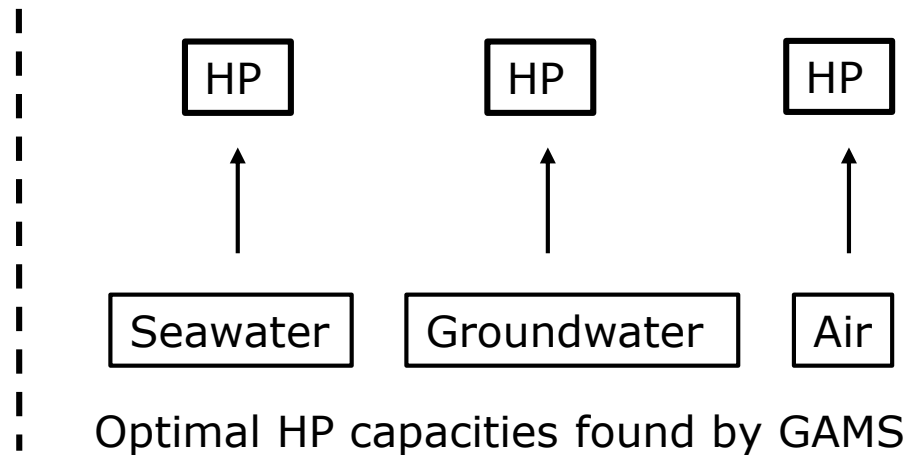
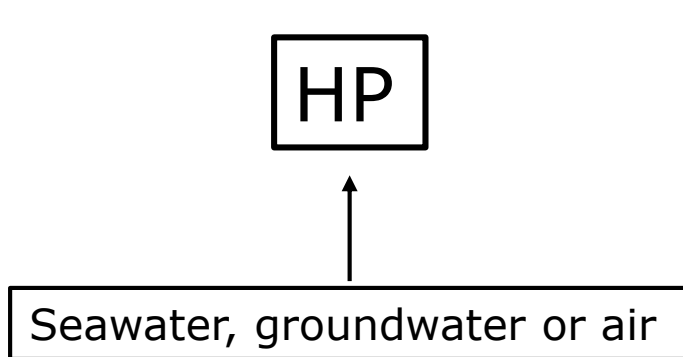
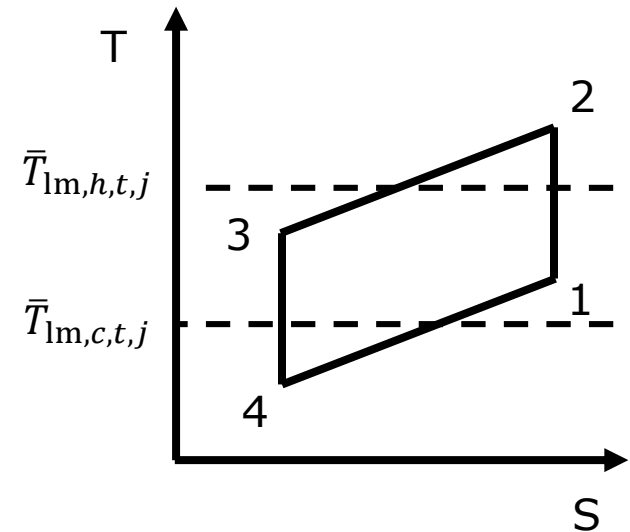
II. Model

- GAMS
- Linear programming
- Lorenz cycle for COP:

$$\text{COP}_{\text{HP},t,j} = \eta_L \text{COP}_{\text{HP},L,t,j} = \eta_L \frac{\bar{T}_{\text{lm},h,t,j}}{\bar{T}_{\text{lm},h,t,j} - \bar{T}_{\text{lm},c,t,j}}$$

η_L : Lorenz efficiency

- Comparison of 3 heat sources in 4 scenarios



II. Key parameters

- Annual mean COP:

$$\text{COP}_{\text{avg}} = \frac{1}{n} \sum_{t=1}^{n=8760} \text{COP}_{\text{HP},t}$$

- Weighted annual system COP:

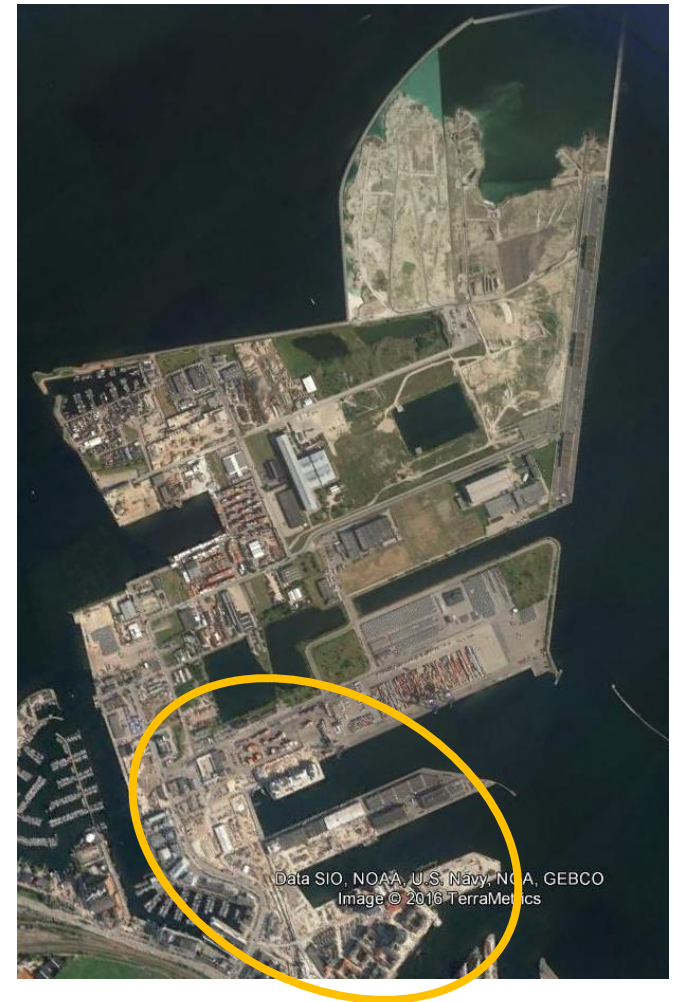
$$\text{COP}_{\text{Sys}} = \frac{\dot{Q}_{\text{sink},\text{sys},\text{tot}}}{P_{\text{sink},\text{sys},\text{tot}}}$$

- Full load hours [h]:

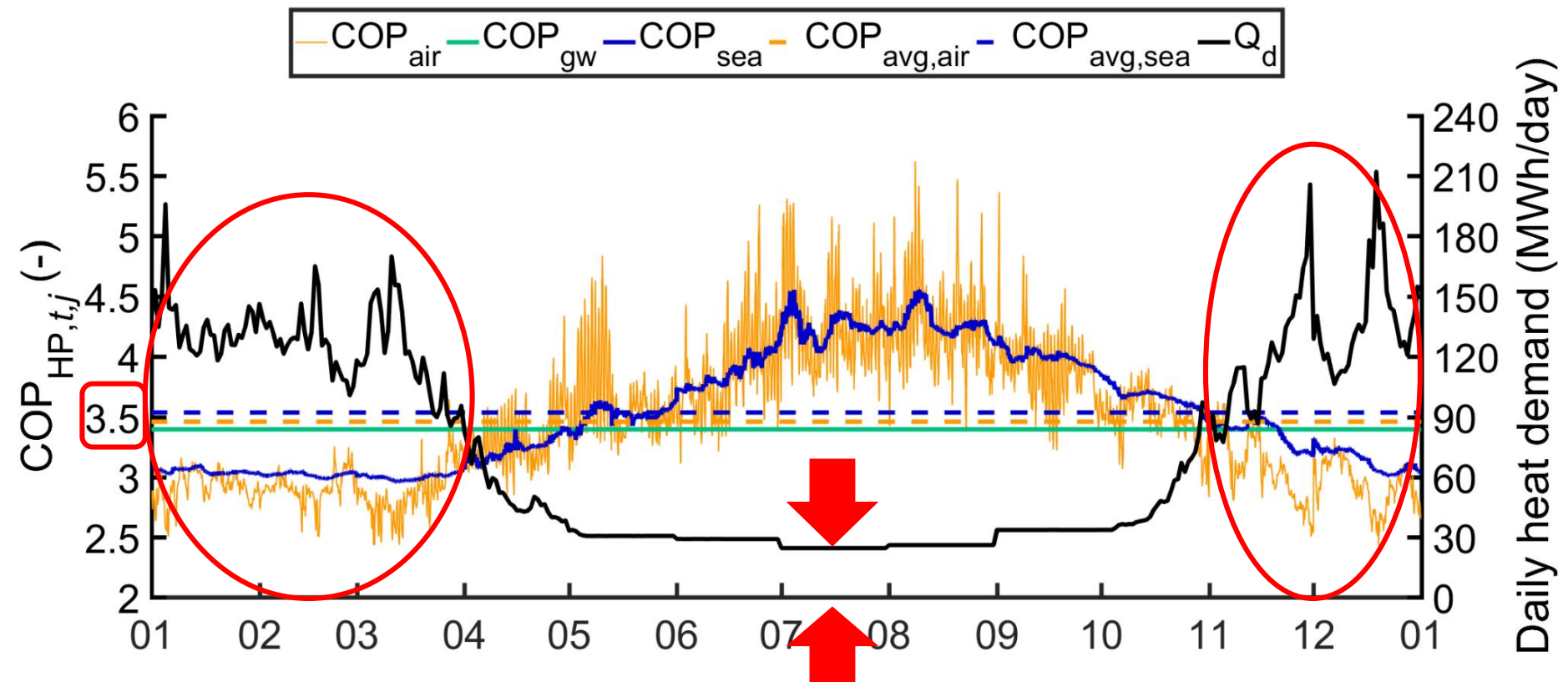
$$\text{FLH}_j = \sum_{t=1}^{n=8760} \frac{\dot{Q}_{\text{sink},t,j}}{\dot{Q}_{\text{sink},d,j}}$$

II. Case description: Nordhavn

- Large development district in Europe
- www.energylabnordhavn.dk
- For this study:
 - Inner Nordhavn: 670,000 m²
 - New residential buildings
 - Space heating: 18 kWh/m²/yr
 - Domestic hot water: 16 kWh/m²/yr
 - Peak demand: 12.4 MWh/h
- 2 cases:
 - *No base load (& Base load)*
 - Total capacity: 80% of peak demand
 - 15 MWh storage
 - Peak boiler when needed



III. COP and heat demand



III. Key parameters

1 MW/7 MW/2 MW

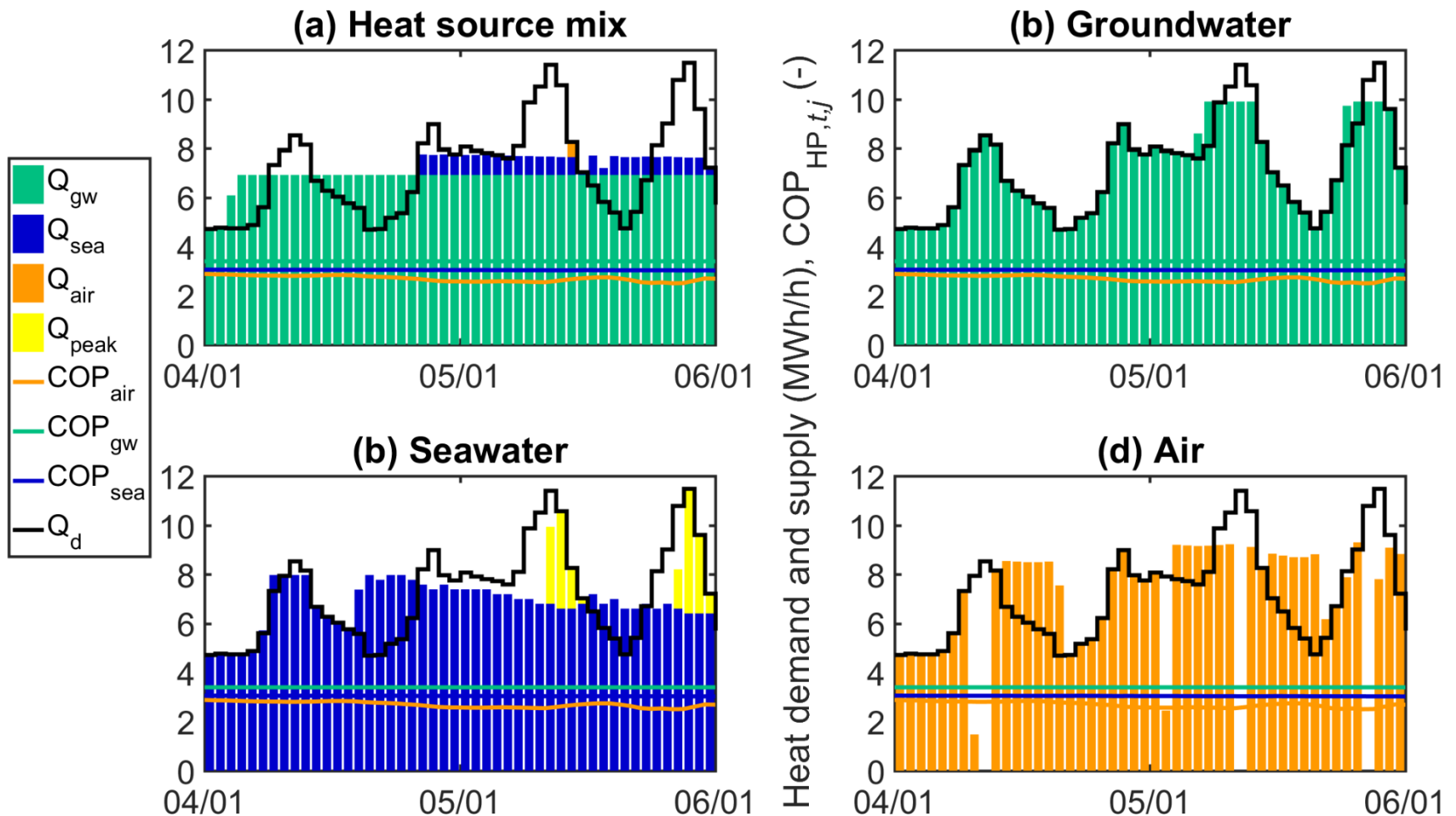
Parameters	Unit	Seawater	Groundwater	Air	Heat source mix: Sea/GW/Air
<i>no base load case</i>					Shares: 9%/56%/15%
Average COP _{avg}	(-)	3.54	> 3.40	< 3.46	3.43
Weighted COP _{sys}	(-)	2.90	< 3.40	> 3.12	3.50
Full load hours HP	(h)	2576	2704	2710	3214/2893/1736

-18%

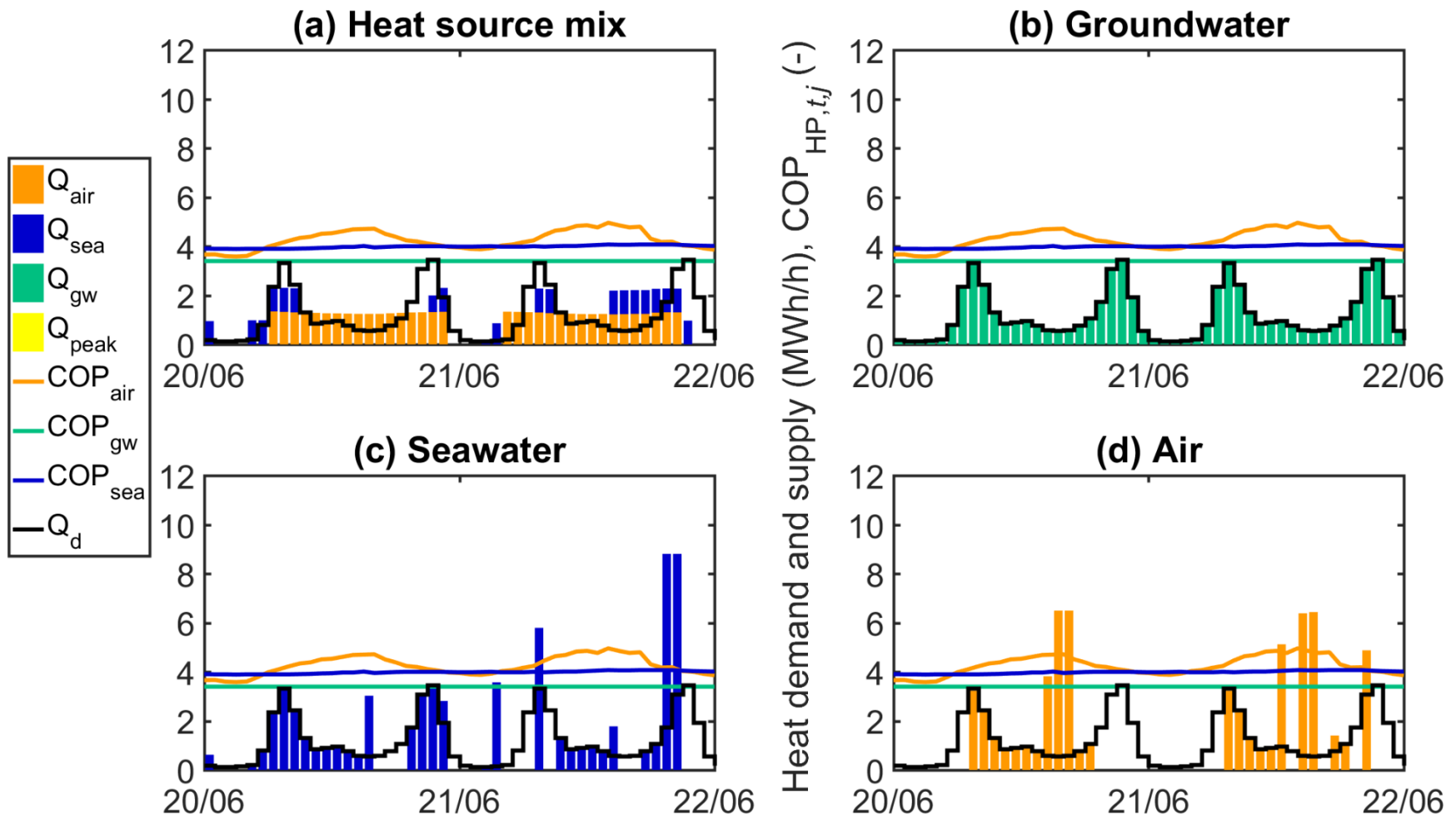
7 MW peak
boiler capacity

COP: +3%

III. Winter: *no base load case*

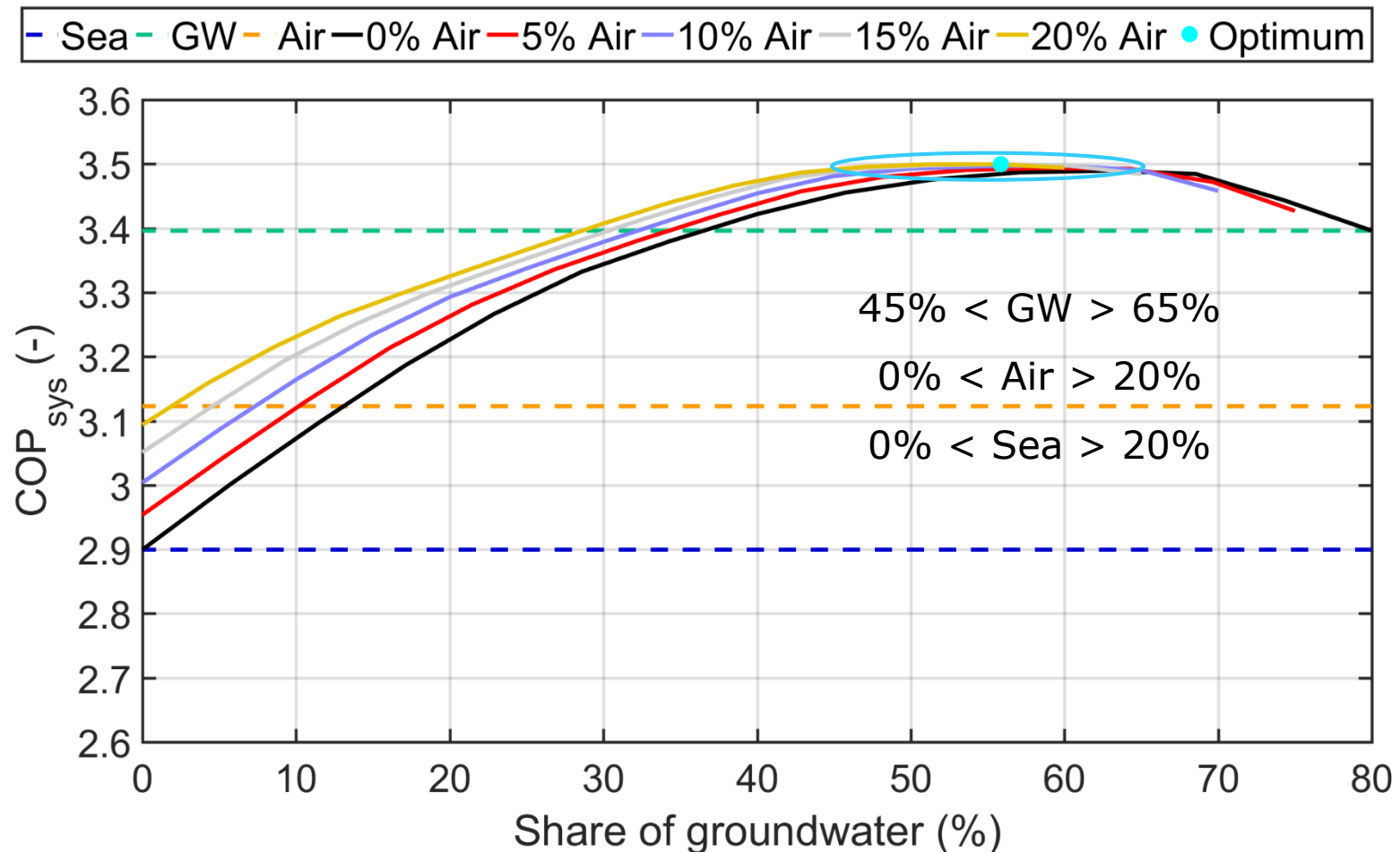


III. Summer: *no base load case*



III. Variation of heat source capacity shares

no base load case



IV. Discussion

Model limitations:

- No auxiliary electricity consumption
- No investment costs
- Constant Lorenz efficiency
- No minimum HP operation level
- Constant electricity price
- Limited to groundwater, seawater and air
- No cooling demand

V. Conclusion

- COP of seawater and air varies a lot
 - Fixed annual COP not recommended without heat demand
 - Weighted COP identified true performance & ranking of heat sources
- High peak unit capacity required for seawater HP
- HPs with combination of heat sources
 - perform better than HP with single heat source
 - utilize heat sources and capacity more effectively
- Recommended range of HP capacities based on peak demand

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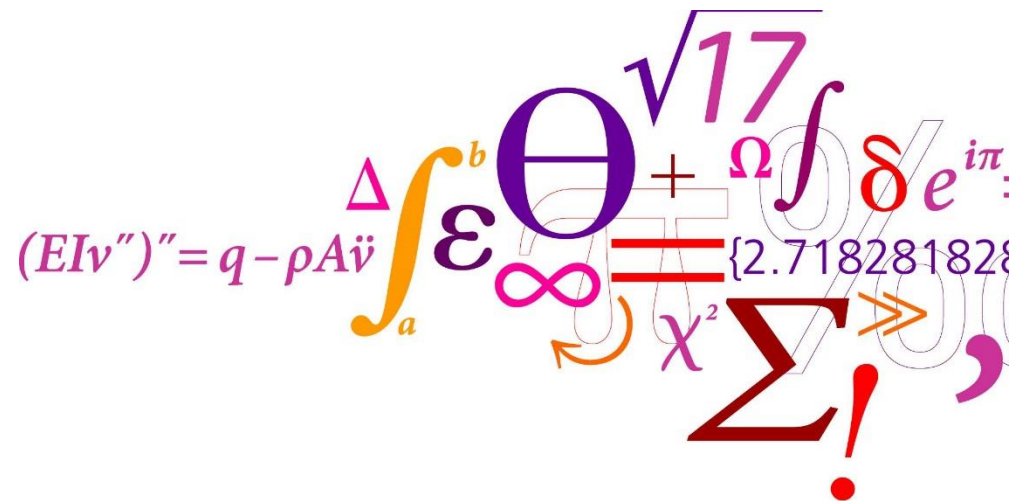
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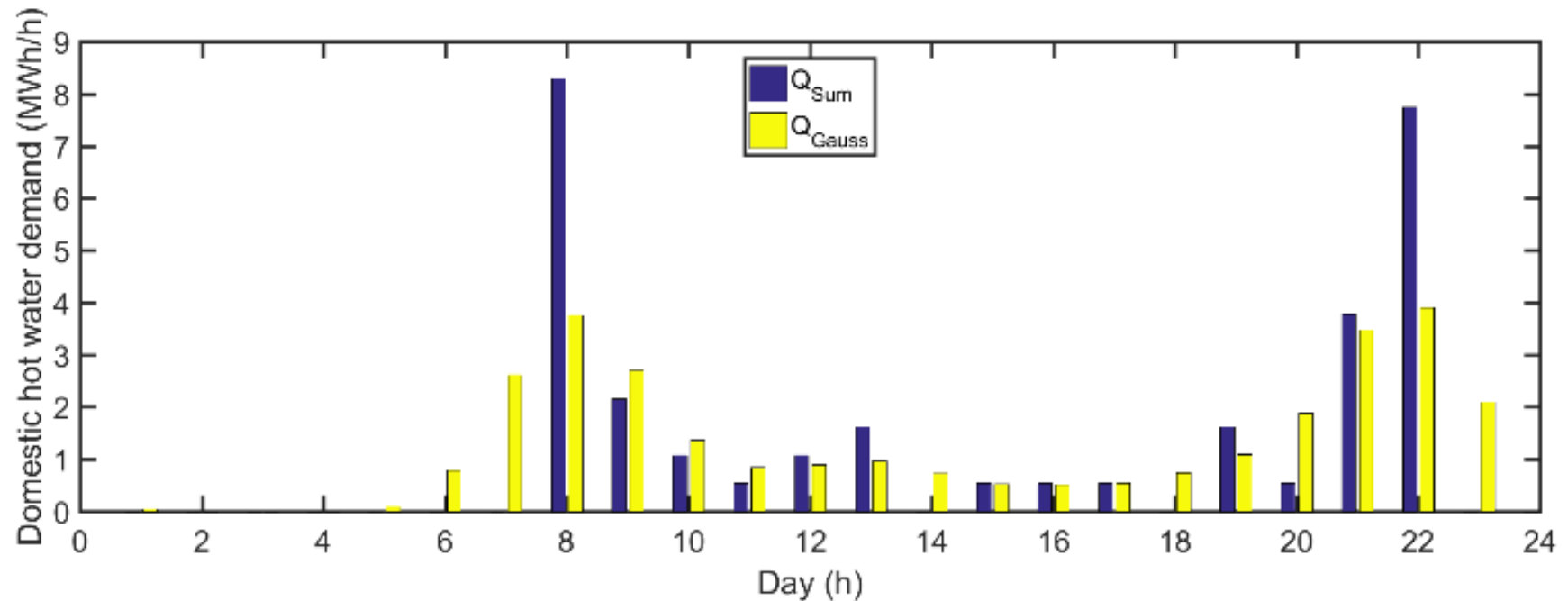
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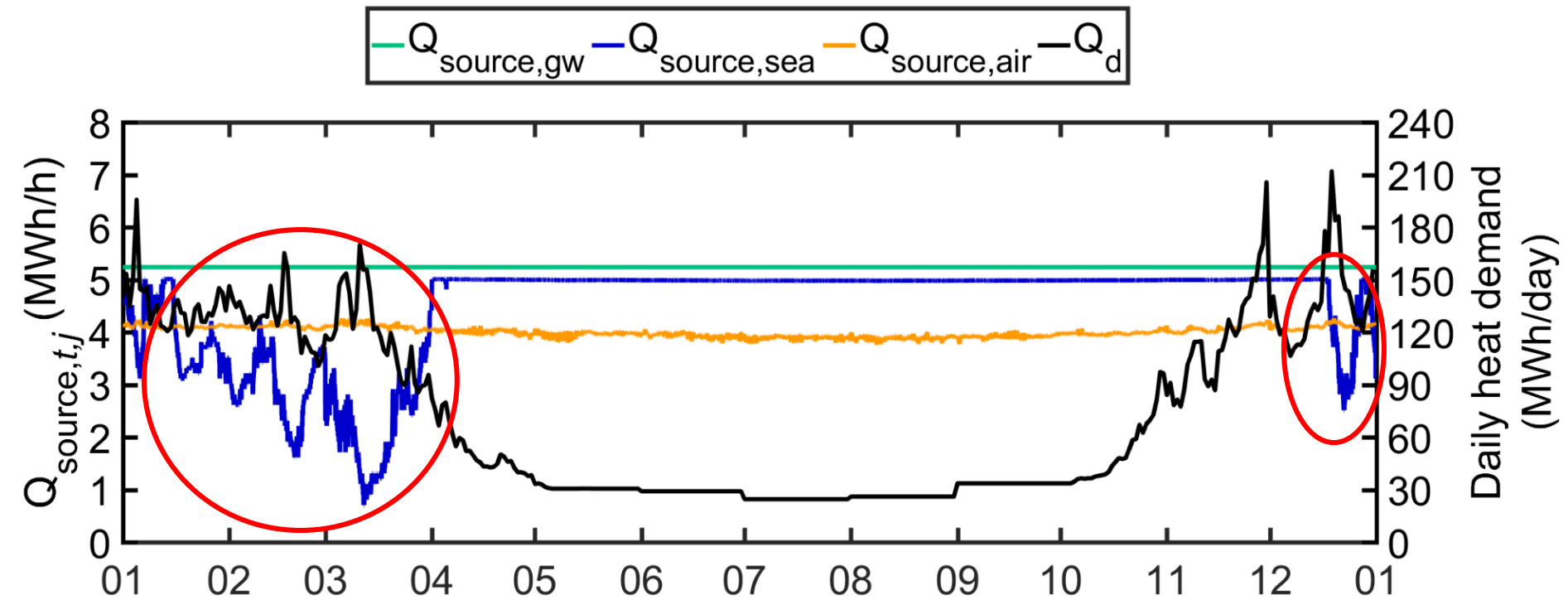
Brian Elmegaard



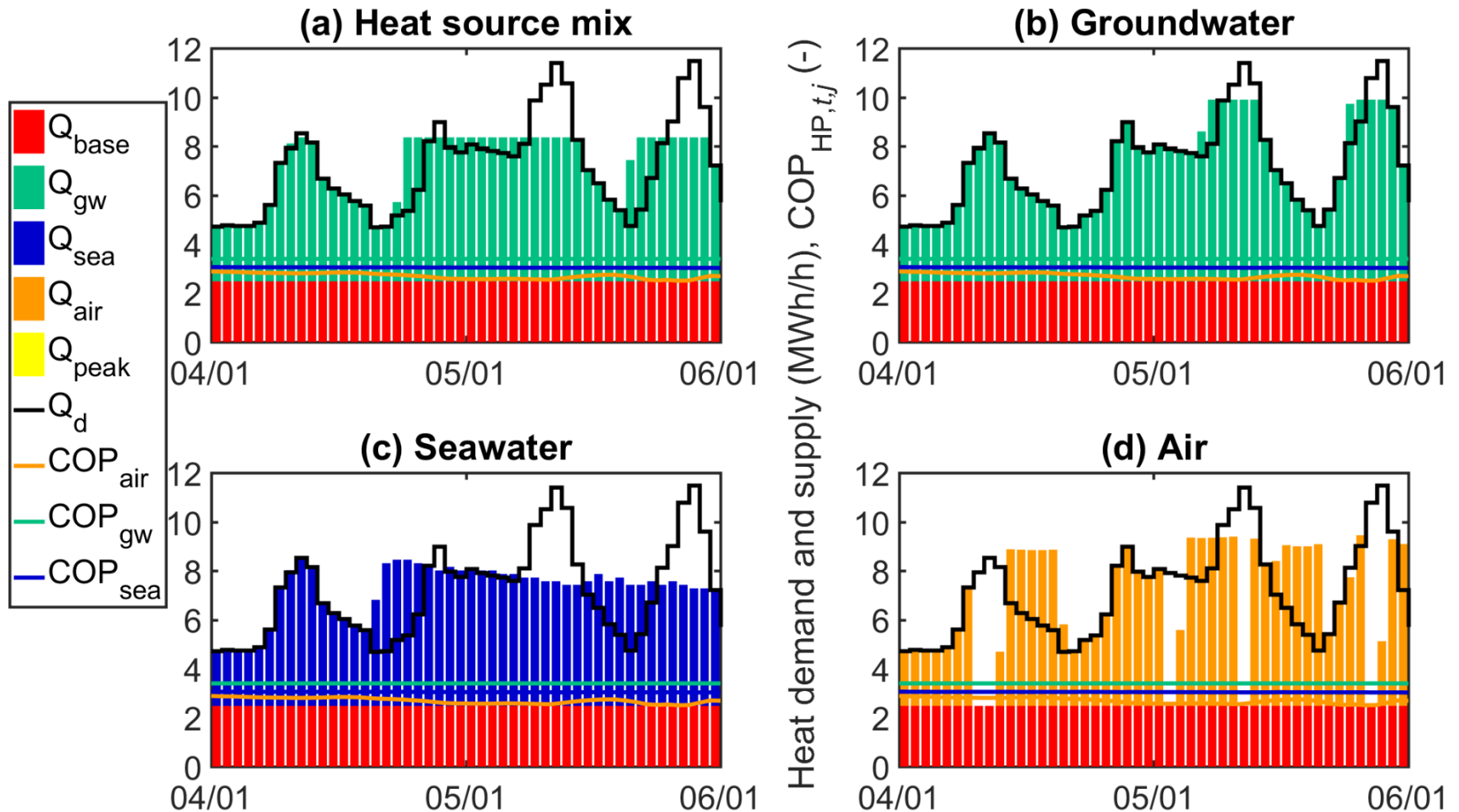
II. DHW + SH demand profile



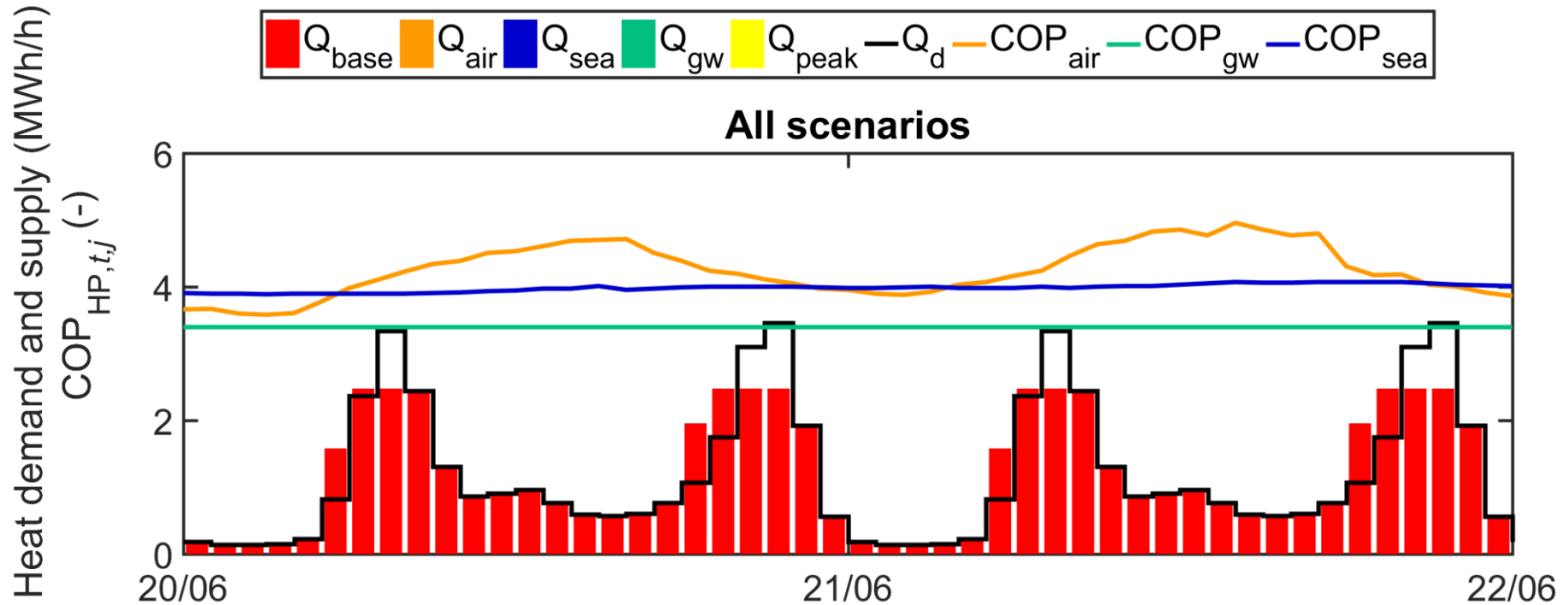
III. Available heat source capacities



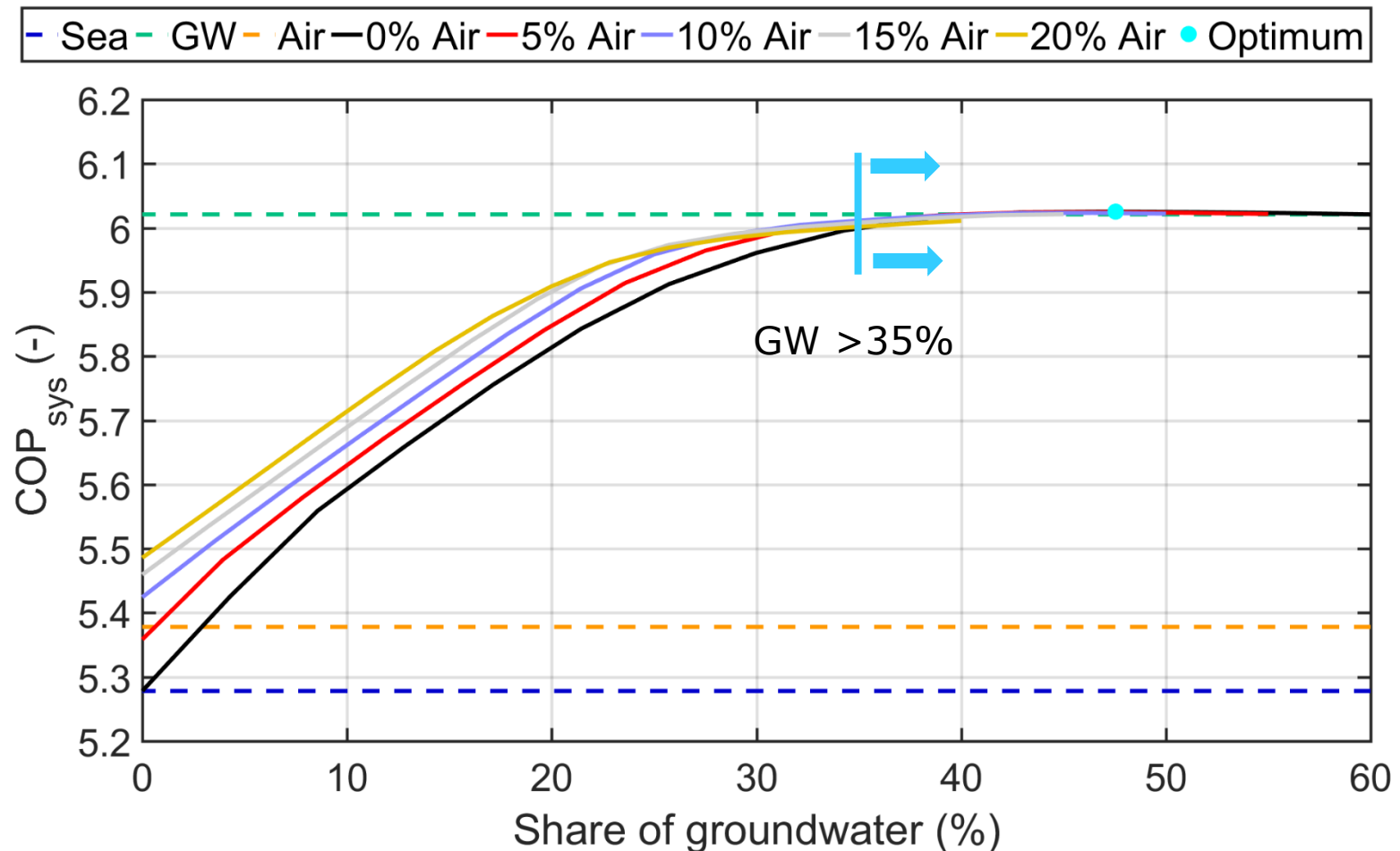
III. Winter: *base load case*



III. Summer: *base load case*



III. Variation of heat source capacity shares *base load case*



III. Key parameters

Parameters	Unit	Seawater	Groundwater	Air	All heat sources: Sea/GW/Air
-12% <i>base load case</i>					Shares: 12%/48%/0.0%
Average COP _{avg}	(-)	3.54	3.40	3.46	3.43
Weighted COP _{HP,w}	(-)	3.10	3.40	2.90	3.40
Weighted COP _{Sys}	(-)	5.28	6.02	5.38	6.03
Full load hours HP	(h)	1358	1414	1417	446/1668/0
<i>no base load case</i>					Shares: 9%/56%/15%
Average COP _{avg}	(-)	3.54	3.40	3.46	3.43
Weighted COP _{HP,w}	(-)	3.27	3.40	3.12	3.50
Weighted COP _{Sys}	(-)	2.90	3.40	3.12	3.50
Full load hours HP	(h)	2576	2704	2710	3214/2893/1736

7 MW peak
boiler capacity

-18%

-8%

COP: +3%

FLH for no base case 90% higher